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(71) Applicant: Exxon Research and Engineering Company
P.O.Box 390 180 Park Avenue
Florham Park New Jersey 07832(US)

(72) Inventor: Metzler, Donald Kenneth
17267 Monitor Avenue
Baton Rouge Louisiana(US)

(72) Inventor: Kresge, Edward Nathan
68 Parlin Lane
Watchung New Jersey(US)

(74) Representative: Dew, Melvyn John et al,
Esso Chemical Ltd. Esso Chemical Research Centre P.O.
Box 1
Abingdon Oxfordshire, OX13 6BB(GB)

(54) Semicrystalline ethylene alpha-olefin copolymers for hot melt adhesives.

(57) Semicrystalline ethylene-alpha-olefin copolymers having a molecular weight of 1,000 to 40,000 and containing from 2 to 20% of at least one alpha-olefin having from 3 to 5 carbons are useful in formulating low viscosity hot melt adhesives, particularly in binary compositions with natural or synthetic resin tackifiers. The adhesives show excellent adhesive properties.

SEMICRYSTALLINE ETHYLENE ALPHA-OLEFIN COPOLYMERS
FOR HOT MELT ADHESIVES

1 This invention relates to hot melt adhesives and in
2 particular to a class of semicrystalline ethylene copolymers
3 and use of same for adhering articles.

4 BACKGROUND OF THE INVENTION

5 In recent years, film and sheeting prepared from a
6 wide variety of polymeric products as well as paper and
7 cardboard have been fabricated into bags, envelopes, boxes,
8 cartons and similar containers. During production of such
9 containers, it is necessary to make a seal where two pieces
10 join together or overlap. Such seals are made by
11 utilization of three principal methods, i.e. liquid adhe-
12 sives, heat-sealing and hot-melt adhesives.

13 Each of such sealing methods has a specific area of
14 utilization. For example, paper, cardboard and wood prod-
15 ucts are frequently bonded using liquid adhesives. These
16 adhesives may include polymers soluble or dispersible in
17 water, such as starches and animal glues. They may also
18 include polymers soluble in organic solvents such as natural
19 rubber or polychlorophene rubber. In recent years, use of
20 these liquid adhesives has become less prominent because of
21 certain disadvantages associated with their use. Since the
22 liquid medium must be removed (absorbed by the substrate or
23 evaporated) in order to form a strong bond, liquid adhesives
24 are inherently time-consuming to use. In addition, the cost
25 of energy to evaporate the liquid and equipment to recover
26 and/or dispose of the liquid (if it is an organic solvent),
27 can add significantly to the total cost of the bonding
28 system. Furthermore, liquid adhesives may not satisfactor-
29 ily bond all substrates (such as polyolefin films), and may
30 swell or stain others (such as paper and cardboard).

31 Polyolefin films, such as those made of polyethylene,
32 are generally heat-sealed since satisfactory adhesives for
33 these materials are not available. Unfortunately, heat-
34 sealing often causes embrittlement of the plastic at the seal
35 and it makes the plastic material thinner at the seal,
36 consequently leading to the formation of weak spots which may

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1 rupture under stress. Moreover, holes are frequently
2 burned in the film if the heat-sealing instrument is too
3 hot or if the time of application is too long.

4 Certain polyolefins, such as biaxially stretched poly-
5 propylene or calendered high density polyethylene cannot
6 be heat-sealed. Accordingly, it is necessary to coat the
7 surface of such polyolefin films with a substance which can
8 be melted and sealed at a temperature lower than that of the
9 film itself. For example, calendered high density poly-
10 ethylene film must be coated with low density polyethylene
11 and heat-sealed below the softening point of the high density
12 material. It is known to use copolymers of ethylene and
13 alpha-olefins as heat sealable coatings, e.g. see German
14 Patent 2,351,923 and U.S. Patent 1,566,077, which teach of
15 such coatings applied to polypropylene film where the ethyl-
16 ene copolymers contain up to 12% of propylene or butylene and
17 10-25% of higher alpha-olefins, respectively.

18 Hot melt adhesives (hereinafter designated HMA)
19 combine some of the advantages of both liquid adhesives and
20 heat sealing methods. HMA are applied in the molten state,
21 but bonded on cooling to form adhesive bonds. Bond formation
22 is fast, as in heat sealing, since solvent removal is not
23 required. Properly selected HMA will not cause softening or
24 embrittlement of polymer film substrates. And unlike heat
25 sealable coatings, HMA can be applied in small amounts only
26 where bonding is required rather than being coated over the
27 entire surface of a polymer film.

28 Three types of polymers are known in the art to be
29 used extensively for HMA: ethylene-vinyl acetate copolymer
30 (EVA); low molecular weight polyethylene (LMPE) and amor-
31 phous polypropylene (APP). These may be used themselves as
32 HMA or, more typically, may be formulated with resins, waxes
33 or other ingredients.

34 Other polymers are also known to be used as HMA,
35 e.g. Canadian patent 856,337 discloses the preparation of
36 copolymers of "lower olefins" (C₂-C₆) with "higher olefins"

1 (C₆-C₁₂), which can be used as hot melt adhesives.

2 In view of the above considerations, the provision
3 of substances which can be used alone or in combination with
4 resins as HMA to adhesively bind materials would be of great
5 benefit to the art.

6 SUMMARY OF THE INVENTION

7 In accordance with the present invention, a wide
8 variety of synthetic and natural materials are joined util-
9 izing, as an adhesive, in part or in whole, a copolymer
10 of ethylene and an alpha-olefin having from 3 to 5 carbons, of
11 semicrystalline morphology and of a molecular weight ranging
12 from 1,000 to 40,000.

13 Briefly, the adhesive of the invention is an adhesive
14 composition comprising a copolymer of ethylene and at least
15 one higher aliphatic alpha-olefin having from 3 to 5 carbon
16 atoms, a molecular weight of from 1,000 to 40,000 and a degree
17 of crystallinity of from 10 to 40%, including optionally a
18 tackifier resin and/or wax, and/or other ingredients.

19 DETAILED DESCRIPTION OF THE INVENTION

20 As disclosed above the novel adhesive compositions
21 of the invention feature in whole or part a semicrystalline
22 (degree of crystallinity 10 to 40%) copolymer of ethylene and
23 at least one alpha-olefin having from 3 to 5 carbons. As used
24 herein, the term copolymer is intended to include terpolymers
25 having three or more monomeric components, prepared from
26 ethylene and two or more alpha-olefins having 3 to 5 carbons.

27 As set forth above, the copolymer adhesives of the
28 present invention are prepared by polymerization of ethylene
29 and at least one other olefinic monomer, the other said
30 monomer being selected from the group consisting of linear or
31 branched alpha-olefins, containing 3 to 5 carbon atoms, such
32 as propylene, 1-butene, 3-methyl-1-butene, 1-pentene and the
33 like.

34 The olefinic copolymer adhesives of the invention may
35 contain from about 2 to about 40 percent by weight of the
36 alpha-olefin and correspondingly from about 98 to about 60
37 percent by weight of ethylene.

1 The composition of the copolymers may be conveniently
2 determined by infrared spectroscopy of cast or pressed polymer
3 films, especially for the case in which the alpha-olefin
4 is propylene. The weight percent ethylene can be calculated
5 using the relationship

$$6 \qquad W_E = 100 / (1 + K (A_{1378} / A_{720}))$$

7 wherein A_{1378} and A_{720} are, respectively, the IR absorbances
8 of the sample at 1378 cm^{-1} and 720 cm^{-1} . K is a constant
9 (normally $K=0.25$), defined as

$$10 \qquad K = 0.5 (A_{720} / A_{1378})$$

11 when measured using a standard ethylene/propylene copolymer
12 of 66.7 wt% ethylene composition. Copolymer composition can
13 also be determined by C^{13} nuclear magnetic resonance spectroscopy.
14

15 The copolymers are prepared by polymerization of
16 the alpha-olefin using an inert diluent such as a suitable
17 aliphatic or aromatic hydrocarbon solvent, e.g. butane,
18 hexane, heptane, mineral spirits, benzene, toluene and the
19 like. Copolymers may also be prepared using the alpha-olefin
20 co-monomer as a diluent.

21 Polymerization is conducted either batchwise or by a
22 continuous process in the presence of a coordination polymerization
23 catalyst comprising (1) an alkyl aluminum or
24 alkyl aluminum halide compound, as described below, and (2)
25 a transition metal halide or oxyhalide, also as described
26 below. Suitable aluminum compounds correspond to the formula
27 $R_n Al_m X_{3m-n}$, wherein R represents an aliphatic or aromatic
28 hydrocarbon radical, Al represents aluminum, X
29 represents a halogen radical, $m = 1$ or 2 , and n is an integer
30 from 1 to 3 . Examples of suitable aluminum compounds
31 include: triethyl aluminum, trimethyl aluminum, diethyl
32 aluminum chloride, sesquiethyl aluminum chloride ($Et_3 Al_2 Cl_3$),
33 ethyl aluminum dichloride, diethyl aluminum bromide, tri-
34 phenyl aluminum, triisobutyl aluminum, etc. Suitable
35 transition metal compounds include halides and oxyhalides
36 of group 4b, 5b, 6b, and 7b metals of the periodic table of
37 elements, including $TiCl_3$, $TiCl_4$, VCl_4 , and $VOCl_3$.

38 Polymerization temperatures range from about 25°C to

1 about 125°C, although somewhat higher or lower temperatures
2 may be used without deleterious effects.

3 The copolymers of the invention may have a range of
4 molecular weights of from 1,000 to 40,000. Molecular weight
5 control is achieved during polymerization by use of a
6 suitable chain transfer agent, such as hydrogen.

7 Molecular weights of the copolymers are preferably
8 determined by gel permeation chromatography (GPC) at 135°C
9 using o-dichlorobenzene as solvent. Membrane osmometry may
10 also be used.

11 Specific gravities of the copolymers can be deter-
12 mined by weighting samples suspended in air and suspended in
13 a non-solvent liquid such as isopropanol. Specific gravity
14 is calculated using the following equation:

$$15 \quad d = d_1 (W_{\text{air}} / (W_{\text{air}} - W_1))$$

16 wherein W_{air} and W_1 are the weights of a given sample or air
17 and in liquid, and d_1 is the specific gravity of the liquid.

18 Degree of crystallinity can be estimated from speci-
19 fic gravity data, using the relationship below which was
20 originally developed for use with low density polyethylene:

$$21 \quad X_c = (6.896 - 5.896/d) \times 100\%$$

22 wherein X_c is the percent crystallinity and d is the specific
23 gravity of the copolymer. Alternatively, degree of crys-
24 tallinity can be measured by X-ray diffraction.

25 The term "hot melt system" is used to refer to
26 compositions applied to a solid substrate in a molten state,
27 the composition developing the specific properties for
28 which it was formulated on cooling. Hot melt systems include
29 hot melt adhesives, hot melt pressure sensitive adhesives,
30 hot melt coatings, laminating compositions, hot melt road-
31 marking compositions and wax blending compositions.

32 The ethylene-olefin copolymer of the invention pre-
33 ferably has an alpha-olefin content of from 5 to 20% by
34 weight.

35 The semicrystalline ethylene copolymers of the in-
36 vention have relatively low molecular weights, and thus
37 relatively high melt indices. It is preferred that mole-
38 cular weight of the copolymers are in the range of 1,000

1 to 40,000, more preferably in the range of 5,000 to 20,000
2 and molecular weights in the range of from 10,000 to 15,000
3 are particularly preferred.

4 Within the range of alpha-olefin content crystal-
5 linity and molecular weight outlined above, the choice of
6 a particular combination of these parameters will be deter-
7 mined by the particular application for which the ethylene
8 copolymer is intended. Increasing the alpha-olefin content
9 has been found to decrease the degree of crystallinity (and
10 as a result decrease the specific gravity) of the copolymer,
11 leading to improvements in flexibility (at room temperature
12 and particularly at low temperatures) and adhesive strength
13 on non-porous substrates, such as aluminum foil or poly-
14 olefin films. When used to adhere relatively low-melting
15 point polyolefin films, such as low density polyethylene
16 (LDPE) or linear low density polyethylene (LLDPE), copo-
17 lyomers with lower ethylene content (about 70 wt% ethylene)
18 show the particular advantage of allowing strong seals to be
19 made without substantially deforming the substrate film. On
20 the other hand, copolymers with higher ethylene content
21 (about 90 wt% ethylene) show improved high temperature
22 properties, such as shear adhesion fail temperature and pop-
23 open temperature, particularly when applied to porous or
24 fibrous substrates, such as paper or cardboard. Thus the
25 copolymers of this invention are suited to a wide variety of
26 substrates and uses by careful selection of the appropriate
27 copolymer composition.

28 Similarly, decreasing the molecular weight of the
29 copolymer results in decreased viscosity of the copolymer
30 and of adhesive blends. Those skilled in the art of hot melt
31 adhesives will recognize that proper control of melt vis-
32 cosity is an important requirement for forming strong ad-
33 hesive bonds. If the viscosity is too high, then the
34 adhesive cannot be applied with conventional hot melt ap-
35 plication equipment. If the viscosity is too low, then
36 the adhesive will tend to soak into porous substrates or to
37 be squeezed out of the bond region on heat sealing. Mole-
38 cular weight is a significant factor in adhesive perfor-

1 mance variable as well. Higher molecular weight provides
2 increased strength and toughness to adhesive bonds, and
3 improves high temperature performance.

4 It is a particular advantage of the invention herein
5 described that not only can copolymer composition and mole-
6 cular weight be varied over wide ranges, but they can be
7 varied independently, (i.e., variation of copolymer com-
8 position has little effect on molecular weight; variation of
9 molecular weight has little effect on composition).

10 The ethylene copolymers of the invention may be used
11 in hot melt systems in a variety of compositions. For some
12 applications the copolymer alone may have sufficient tack in
13 the molten state to be used alone as a hot melt composition,
14 without addition of any tackifier or wax, although possibly
15 with small amounts of additives such as antioxidants which
16 are conventional in hot melt compositions. The ethylene
17 copolymers may also be used in ternary compositions in
18 conjunction with both a tackifier and a wax, but the vis-
19 cosity of the copolymer of the invention is such that for
20 most applications the addition of a wax as a viscosity
21 improver is not needed.

22 In a further aspect the invention provides a HMA
23 composition comprising an ethylene copolymer of the inven-
24 tion and a tackifier.

25 A tackifier employed in such binary compositions may
26 be a natural or a synthetic resin. Among the natural resins
27 which may be employed are the polyterpenes, rosins, rosin
28 esters and derivatives, as well as their hydrogenated forms.
29 Various synthetic petroleum resins may be employed, and
30 suitable resins include products obtained by thermal or
31 catalytic polymerization of aliphatic (including cyclic ole-
32 fins) and/or aromatic hydrocarbons and hydrogenated deri-
33 vatives thereof, as well as mixtures of such resins. By way
34 of example, the so-called aliphatic resins may be obtained by
35 polymerization of C₅ naphtha fractions containing C₅ con-
36 jugated diolefins such as isoprene, 1,3-pentadiene or
37 mixtures thereof, or these fractions with other components
38 such as cyclopentadiene, methyl cyclopentadiene or their

1 dimers or codimers. Optionally these resins may be hydro-
2 genated. The so-called aromatic resins may be obtained by
3 polymerizing a petroleum fraction containing polymerizable
4 aromatic hydrocarbons such as styrene, alpha-methylstyrene,
5 vinyl toluene, vinyl xylene, propenyl benzene, indene,
6 methyl indene and ethyl indene, and optionally hydrogenating
7 the resultant resin. Other chemically modified resins may
8 also be used, for example modification with alpha-unsaturated
9 acid or anhydride. Examples of other resins include mixed
10 aliphatic/aromatic resins and modified terpene resins such
11 as phenolic modified terpene resins.

12 The binary HMA compositions of the invention may
13 contain the ethylene copolymer and tackifier in a weight
14 ratio of from 95:5 to 5:95. A high proportion of ethylene
15 copolymer tends to result in high viscosity, better cohesive
16 strength and toughness, whereas high resin content tends to
17 produce more brittle products with a greater cold stickiness.
18 Preferably the ethylene copolymer and tackifier are present
19 in a weight ratio of from 95:5 to 50:50, and most preferably
20 the binary compositions contain from 60 to 90% by weight of
21 the composition of ethylene copolymer. However, it is a
22 feature of the binary compositions that the properties of the
23 binary composition do not vary as significantly as in con-
24 ventional ternary compositions with varying ratios of ethyl-
25 ene copolymer and tackifier. Thus, while ternary composi-
26 tions are frequently formulated for particular applications
27 within relatively narrow ranges of ethylene copolymer, wax
28 and tackifier content, the binary compositions show much
29 greater flexibility, as well as greater predictability in
30 terms of their behavior and performance.

31 As already indicated the binary compositions have low
32 viscosity without having to resort to the addition of waxes.
33 The viscosity chosen for a conventional HMA depends on its
34 intended application. By way of example, conventional HMA
35 compositions intended for packaging applications are for-
36 mulated to give a viscosity 500 to 5000 Milli Pascal seconds
37 mPa.s (at 180°C), while for bookbinding a viscosity of 3,000
38 to 10,000 mPa.s (at 180°C) is generally more appropriate. It

1 is a feature of the binary compositions of the present
2 invention that the overall viscosity is low enough to give the
3 HMA acceptable handling properties, without resulting in an
4 undesirable reduction in other properties.

5 For particular applications, it may be appropriate
6 for the binary compositions of the invention to contain other
7 components common in HMA formulation. Thus, for example, the
8 compositions may also contain other polymers, antioxidants,
9 plasticizers, fillers and flow improvers.

10 HMA prepared in accordance with this invention may be
11 used to bond a variety of substrates including metals such as
12 aluminum, polyolefins such as polyethylene and polypropy-
13 lene, other polymers such as polyvinylchloride, polyamides
14 and polyesters, paper, treated and untreated cardboard and
15 wood. The HMA are useful in a wide range of applications such
16 as wood-working, bookbinding, assembly of electronics, packaging,
17 coating, laminating and in sanitary goods. The HMA of the
18 invention are believed to be particularly useful in applications
19 where good cold flexibility is required such as in packaging
20 goods for storage at low temperatures, and in applications
21 where a wide range of temperature may be expected.

22 Other possible applications for the HMAs of the in-
23 vention include mold release agents, color masterbatch
24 additives, paint and printing ink additives, toners, plas-
25 tics additives, asphalt additives, plastisols, fruit coating
26 agents and rubber processing aids.

27 The following illustrative examples will serve to
28 more fully exemplify the preparation and utility of the
29 copolymer adhesives of the present invention.

30 EXAMPLE 1: PREPARATION OF ETHYLENE/PROPYLENE COPOLYMER

31 The copolymer was prepared in a one gallon stainless
32 steel continuous flow stirred tank autoclave-type reactor,
33 equipped appropriately to control reactor temperature and
34 pressure and the flow rates of various reactor feedstreams.
35 Polymerization was carried out at 65°C, under pressure of 200
36 psig. Raw materials and feed rates were as follows:

1	Hexane (solvent)	11750 g/hr
2	Ethylene	915
3	Propylene	400
4	Hydrogen	1.28
5	VOCl ₃	2.87
6	Et ₃ Al ₂ Cl ₃	14.4

7 Polymerization was terminated at the reactor outlet by in-
8 jection of a small amount of isopropanol into the outlet
9 stream. The polymer/hexane solution coming from the reactor
10 was washed with slightly acidic water to remove catalyst
11 residue. The solution was then pumped into a drum of
12 vigorously agitated hot water (80°-90°C), causing the hexane
13 to evaporate. Coagulated polymer was dried under vacuum to
14 remove residual hexane and water.

15 Analysis of the product yielded the following
16 results:

17	Composition (wt% C ₂)	80.5
18	M _w by GPC	17200
19	Specific gravity	0.874
20	Degree of crystallinity (%)	15.0

21 EXAMPLE 2:

22 PREPARATION OF ETHYLENE/PROPYLENE COPOLYMER

23 The copolymer was prepared and recovered as described
24 in Example 1, but using the reactor feed rates indicated
25 below:

26	Hexane (solvent)	11 750 g/hr
27	Ethylene	915
28	Propylene	207
29	Hydrogen	2.08
30	VOCl ₃	2.87
31	Et ₃ Al ₂ Cl ₃	14.7

32 The following analytical results were obtained:

33	Composition (wt% C ₂)	89.0
34	M _w by GPC	8700

1	Specific gravity	.895
2	Degree of crystallinity	30.8

3 EXAMPLE 3:

4 PREPARATION OF ETHYLENE/PROPYLENE COPOLYMER

5 The copolymer was prepared as described in Example 1,
6 except that proportions of reactants were changed and cyclo-
7 hexane was used as the solvent. Raw materials and feed rates
8 were as follows:

9	Cyclohexane	13.400	g/hr
10	Ethylene	915	
11	Propylene	538	
12	Hydrogen	1.66	
13	VOCl ₃	2.87	
14	Et ₃ Al ₂ Cl ₃	12.6	

15 The product was washed and recovered as described in Example
16 1. Analysis found the following:

17	Composition (wt% C ₂)	71.3
18	\bar{M}_w (by GPC)	9970
19	Specific gravity	.873
20	Degree of crystallinity (%)	14.2

21 EXAMPLE 4

22 PREPARATION OF BINARY HMA COMPOSITIONS

23 Several polymers, prepared in essentially the same
24 manner as described in Example 1, but with varying propor-
25 tions of ethylene, propylene and hydrogen in the reactor
26 feed, were formulated as binary HMA compositions. Each blend
27 was prepared in a laboratory beaker equipped with an air-
28 driven stirrer and electric heating mantle. Polymer and
29 additives were charged to the beaker and agitated slowly
30 while being heated. When the polymer (now molten) reached
31 300°F, a petroleum resin (Escorez 1304 sold by Exxon Chemical
32 Americas, Houston, Texas) was added. The mixture was blended
33 for 15 minutes at 300°, then poured out onto a cold surface

1 and allowed to solidify. The following test results were
2 obtained:

3		<u>A</u>	<u>B</u>	<u>C</u>	<u>D</u>
4	<u>Polymer</u>				
5	Composition (wt% C ₂)	72	80.5	89	72.5
6	M _w by GPC	17200	15400	8700	25800
7	<u>Adhesive blend</u>				
8	Viscosity @350°F (Brookfield)	6750	3100	1490	11800
9	Shear Adhesion				
10	Fail Temp (°C)	48	61	80	51
11	Brittleness Temp (°C)	-	-13	26	-39
12	Peel Strength on Paper				
13	(lbs/in)	.55	.68	.43	.71

14 All of the four binary adhesive blends exhibit pro-
15 perties as seen from the above Table which make each blend
16 useful in certain HMA applications. Blends B and D exhibit
17 excellent low temperature flexibility and would be useful for
18 low temperature (sub-zero) packaging. Blend C exhibits good
19 high temperature performance and low melt viscosity. Blend
20 A is a general purpose HMA.

CLAIMS

1. An adhesive composition comprising a copolymer of ethylene and at least one higher aliphatic alpha-olefin having from 3 to 10 carbon atoms, a molecular weight of from 1,000 to 40,000 and a degree of crystallinity of from 10 to 50%.
2. A composition according to claim 1, wherein the higher alpha-olefin has from 3 to 5 carbon atoms.
3. A composition according to claim 2, wherein the higher alpha-olefin is propylene.
4. A composition according to claim 2, wherein the higher alpha-olefin is selected from the group consisting of 1-butene, 3-methyl-1-butene and 1 pentene.
5. A composition according to any of the preceding claims wherein the higher alpha-olefin is present in the copolymer in from 2 to 20 weight percent.
6. A composition according to any of the preceding claims wherein the copolymer has a degree of crystallinity of from 10 to 40%.
7. A hot melt adhesive composition comprising (1) a copolymer of ethylene and at least one higher aliphatic alpha-olefin having from 3 to 10 carbon atoms, a molecular weight of from 1,000 to 40,000 and a crystallinity of from 10 to 50%, and (2) a tackifier.
8. A composition according to claim 7, wherein the copolymer has a molecular weight of from 1,000 to 20,000.

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9. A composition according to claim 7 or 8, in which the tackifier is a resin, resin ester, resin derivative or a hydrogenated derivative thereof.
10. A composition according to claim 9, in which the tackifier is one or more petroleum resins obtained by thermal or catalytic polymerization of aliphatic and/or aromatic hydrocarbons or hydrogenated derivatives thereof.
11. A composition according to any of claims 7 to 10, in which the weight ratio of said copolymer to said tackifier is from 95:5 to 5:95.
12. A composition according to claim 11, in which the weight ratio of said copolymer to said tackifier is from 95:5 to 50:50.